PB90-262825

Radon Diagnostics for Schools

(U.S.) Environmental Protection Agency, Research Triangle Park, NC

1990

U.S. Department of Commerce
National Technical Information Service
NTIS

AEERL-P-667

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before complet

1. REPORT NO. EPA/600/D-90/105	2.
3. PB90-262825	
4. TITLE AND SUBTITLE Radon Diagnostics for Schools	5. REPORT DATE
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) K.W. Leovic, A.B. Craig, and D.B. Harris	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS See Block 12	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. NA (Inhouse)
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development; Air and Energy Engineering Research Laboratory, Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Published paper; 1/88-4/90
	14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES AEERL project officer is Kelly W. Leovic, Mail Drop 54, 919/541-7717. Presented at Annual AWMA Conference, Pittsburgh, PA, 6/24-29/90.

16. ABSTRACT The paper discusses a systematic approach to conducting radon diagnostics in schools. It provides those with radon mitigation experience in houses with an understanding of the major differences between schools and houses and how these differences influence radon diagnostics in schools. The diagnostic procedures and measurements discussed include: a review of all radon screening and confirmatory measurements; a review of all available building specifications and drawings such as structural, mechanical, and electrical; a building investigation to assess potential radon entry routes and to confirm and supplement information cited in the building plans; an analysis of the heating, ventilating, and air-conditioning (HVAC) system and its influence on pressure differentials and radon levels; and, most importantly for schools considering installation of a subslab depressurization system, the recommended approaches for measuring subslab pressure field extension. Radon diagnostic protocols for schools need to be more extensive than those applied in houses since schools are typically much larger than houses and often have complex structural details and HVAC systems. EPA radon mitigation experience in schools in Maryland, North Carolina, and Tennessee has been combined with initially used techniques in houses to produce recommended approaches for use with schools.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Radon	Stationary Sources	07B
School Buildings	Diagnostics	13M, 05I
Measurement		14G

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 10
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA 22161

PB90-262825

EPA/600/D-90/105

90-89.3

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ABSTRACT

EPA's Air and Energy Engineering Research Laboratory (AEERL) has been researching radon diagnostic and mitigation approaches for schools for almost 2 years. Initially, radon diagnostic techniques for houses were used in schools and, through radon diagnostics and mitigation experiences in schools located in Maryland, North Carolina, Tennessee, and Virginia, these diagnostic protocols have been modified to incorporate the unique characteristics of school buildings. A systematic approach to conducting radon diagnostics in schools is discussed. The paper is intended to provide those with radon mitigation experience in houses with an understanding of the major differences between schools and houses and how these differences influence radon diagnostics in schools. The diagnostic procedures and measurements discussed include: a review of all radon screening and confirmatory measurements; a review of all available building specifications and drawings such as structural, mechanical, and electrical; a building investigation to assess potential radon entry routes and to confirm and supplement information cited in the building plans; an analysis of the HVAC system and its influence on pressure diferentials and radon levels; and, most importantly for schools considering installation of a subslab depressurization system, the recommended approaches for measuring subslab pressure field extension.

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INTRODUCTION

Radon mitigation experience in schools to date has focused on subslab depressurization (SSD) since it has been the most universal and successful mitigation technique for houses. Sealing of radon entry routes and pressurization through the heating, ventilating, and air-conditioning (HVAC) system have also been studied in a few schools. The radon diagnostic approaches discussed in this paper are largely based on diagnostic and mitigation experiences in schools located in Maryland, Virginia, North Carolina, and Tennessee. For more detailed guidance on radon reduction in schools, the reader should refer to the EPA document "Radon Reduction Techniques in Schools - Interim Technical Guidance (1)."

School buildings have a number of physical characteristics that make them different, and typically more complex, than residential houses. These characteristics include: building size and substructure, HVAC system design and operation, and locations of utility lines. These physical characteristics can influence radon levels in the building since they affect radon entry routes, building pressure differentials, and radon mitigation approach. Since it is crucial that they are understood when conducting radon diagnostics in a school, the relevance of these building characteristics to radon entry and mitigation are briefly discussed below.

Building Substructure

The three basic substructure types are slab-on-grade, basement, and crawl space. Schools often have one or more additions, and each addition may have a different type of substructure. This paper focuses on slab-on-grade and basement schools, since experience in crawl space schools is very limited.

SSD has been applied successfully in a number of slab-on-grade schools that are underlain with clean, coarse aggregate. However, if the slab is poured directly on tightly packed soil with poor permeability rather than on aggregate, SSD is not reasonably applicable or may require many suction points.

Due to their large size, school buildings often have interior footings and/or thickened slabs. These may create subslab barriers to airflow and, consequently, limit the applicability of a subslab depressurization system. The location and design of these barriers will affect the number and placement of subslab depressurization points. If all block walls surrounding the classrooms extend to footings creating subslab compartments, it will probably be necessary to install a suction point for every room, although one suction

point for two rooms has been adequate in some cases. (This is discussed further in the section on "Subslab Pressure Field Extension Measurements.") If the walls between rooms are set on thickened slabs rather than on below grade walls resting on footings, subslab depressurization from one suction point will usually extend under these thickened slab areas.

Another structural concern is concrete block walls that penetrate the slab, rest on the footings, and have openings into the rooms and/or the overhead plenum. Radon-containing soil gas can enter the hollow block walls from below grade and can be pulled into the building by the negative pressures created by the HVAC system. Unducted return-air plenums in the drop ceiling or ceiling mounted fan-coil units can pull in the radon from the unsealed top blocks or from penetrations through the hollow block walls. Radon may then be distributed throughout the air-handling system with recirculated room air.

Heating, Ventilating, and Air-Conditioning (HVAC) Systems

Pressure differentials that contribute to radon entry in schools typically result from operation of a HVAC system under conditions that cause negative pressures (in the building relative to the subslab area), indoor/outdoor temperature differentials (the "stack effect"), use of appliances or other mechanical devices that depressurize the building, and wind.

HVAC systems in schools and other large buildings vary considerably and tend to have a greater impact on radon levels than do HVAC systems in houses. If the HVAC system induces a negative pressure in the building relative to the subslab area, radon entry into the building will be increased. If the HVAC system pressurizes the building, it can greatly reduce radon entry into the building as long as the fan is operating. However, school HVAC systems are normally set back or turned off on evenings and weekends so, even if the HVAC system pressurizes the school during operation, radon levels may increase during setback periods (2).

Types of HVAC systems in school buildings include: central air-handling systems (supply and/or exhaust), unit ventilators, fan-coil units, and radiant heat. The central air-handling systems and unit ventilators are typically designed to provide outdoor air to the occupied areas and would pressurize the building if operated as designed. However, as a result of concern about increased energy costs, many outdoor-air intakes in school buildings have been deactivated or closed during temperature extremes.

The pressures generated by all HVAC systems in a school influence the pressure relationship between the building interior and the subslab area. Some schools use exhaust fans to increase outdoor air infiltration into the building. Additionally, many schools have separate exhausts (either powered or passive) in areas such as corridors, restrooms, kitchens, cafeterias, locker rooms, gymnasiums, and laboratories. If more air is exhausted from the building than supplied, the building (or zones of the building) will be under negative pressure, increasing radon entry. School HVAC systems and radon

entry are discussed in more detail in a subsequent section, "Analysis of the HVAC System."

Locations of Utility Lines

The location of entry points for utility lines can have a significant influence on radon levels since the lines provide entry routes for radon from the soil gas into the indoor air. Utility lines for HVAC, plumbing, and electrical, for example, that penetrate the slab or wall are frequently not well sealed. If the building is under negative pressure as discussed above, radon can readily enter through these penetrations.

Many slab-on-grade schools locate utility lines in subslab utility tunnels. These tunnels normally have many openings to the soil gas and, as a result, radon can pass into the tunnel and enter the building interior through utility line penetrations (e.g., risers to unit ventilators). It should be noted that utility lines located overhead should not be a problem as far as radon entry is concerned unless wall penetrations have not been sealed.

DISCUSSION OF DIAGNOSTIC PROCEDURES

The radon diagnostic procedures for school buildings discussed below include: a review of all radon screening and confirmatory measurements; a review of all available building specifications and drawings including structural, mechanical, and electrical; a thorough building investigation to assess potential radon entry routes and to confirm and to supplement information cited in the building plans; an analysis of the HVAC system design and operation and its influence on pressure differentials and radon levels; and, most importantly for schools considering installation of a subslab depressurization system, the recommended techniques for measuring subslab pressure field extension.

Review of Radon Screening and Confirmatory Measurements

Initial radon screening, confirmatory measurements, and any additional measurements should follow EPA's interim radon measurement protocol as closely as possible (3). The measurement results should be written on a copy of the school floor plan, along with a description of measurement conditions. Potentially important measurement conditions include: operational status of HVAC system(s), weather (outdoor temperature, precipitation, wind, etc.), and occupied or unoccupied status.

When analyzing the results consider the following questions: Are rooms with elevated radon levels clustered? Does the entire building have elevated radon levels? Are there only a few widely separated rooms with elevated radon levels? The answers to these questions should help target areas of primary interest for the building investigation.

Review of Building Plans

All building plans and specification documents should be obtained for review. Pertinent drawings include architectural, structural, mechanical,

and electrical. The following summarizes the pertinent information typically provided by these plans.

The architectural drawings will give general information on building design and also provide details on typical wall sections.

The structural drawings will contain information on the foundation, footing and thickened slab locations, and subslab fill. These will be helpful to assess the potential effectiveness of a SSD system by indicating the presence and thickness of subslab aggregate and any barriers to subslab communication such as below-grade walls. The structural drawings may also provide clues to possible radon entry routes such as expansion joints.

The mechanical drawings and specifications will provide information on the HVAC system design (such as duct system design, duct run length, supply/return air flow design capacity, outdoor air intakes, and exhaust systems). The mechanical specifications (Division 15) should summarize the HVAC system and identify equipment. For schools with intra-slab radiant heat systems, the plans are particularly important in locating subslab piping prior to measuring subslab communication. Where applicable, the balancing report should also be consulted. Note that 7 liters per second of outdoor air per person is suggested for classrooms in the latest American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) indoor air quality standard (4).

The plumbing and electrical drawings should initially be reviewed for potential radon entry routes. If subslab communication is to be measured to determine the potential for a SSD system, these plans must be studied to determine the locations of subslab utility lines prior to drilling test holes through the slab. Even if plumbing and/or electrical lines are run under the slab, review of the plans will usually reveal suitable locations for test holes.

Building Investigation

A thorough building investigation should be conducted to assess potential radon entry routes and confirm information cited in the building plans. Entry routes include floor/wall cracks, unsealed (or deteriorated) expansion joints, utility penetrations, and open pores of block walls or unsealed tops of block walls that penetrate the slab (5). As the types and magnitudes of radon entry routes are identified, the feasibility of sealing may be considered. However, experience to date has indicated that, since radon entry routes in schools can be so extensive, in most cases sealing alone will probably not reduce radon levels beyond 50 percent due to the impracticality of achieving a near perfect seal. (Note that sealing in houses rarely exceeds 50 to 70 percent reductions in radon levels.)

A chemical smoke stick can be used to determine the direction of air movement through potential entry routes, and a micromanometer can be used to determine the magnitudes of pressure differentials under various HVAC system operational modes. It is also useful to have some type of continuous radon monitor capable of sampling potential radon entry routes. Observations made

during the building investigation should be compared to the radon measurements and correlations noted.

Analysis of the HVAC System

The HVAC system can be evaluated during the building investigation or separately. As mentioned above, the HVAC system can have significant influences on pressure differentials in a school building. The school engineer or other knowledgeable person(s) responsible for operation and maintenance of the HVAC system should be present during the analysis.

The first step is to confirm information found in the mechanical plans and specifications. Is the HVAC system actually installed and/or operated as designed or, for example, have outdoor air intakes been restricted causing the building to be under negative pressure?

A chemical smoke stick can be used to determine whether the building envelop is pressurized or depressurized relative to the outdoors, hallway, or subslab, and a micromanometer can be used to quantify the pressure differentials. When analyzing the pressure differentials induced by the HVAC system, it is important that measurements be made under "typical" operating conditions. Depending on the type of HVAC system and the testing constraints of a given school district, these may or may not be the same conditions under which screening and confirmatory measurements were made. It is still important to ascertain the actual operating mode of the HVAC system. To measure airflow through HVAC registers requires a flow hood. Airflow measurements in ducts and pipes can be measured using an anemometer or a Pitot tube in conjunction with a sensitive pressure gauge.

If the HVAC system is causing the building to be under negative pressure, is this a result of the HVAC system design or is it due to operation and maintenance practices? If the system has the design capacity to maintain all building zones under positive pressure, it may be possible to control radon levels by adjustment of the HVAC system by a qualified person. If HVAC pressurization is under consideration as a permanent approach for radon control, the additional operation and maintenance costs must be considered, and the school maintenance personnel must thoroughly understand the proper system operation. Equipment and/or procedures to identify inadequate HVAC operation are also important.

If it is suspected that radon is being distributed in the school by the air-handling system (with a central HVAC system or unit ventilators), radon "sniffs" in the supply air should be compared with radon levels in the room(s). Elevated levels of indoor radon caused by radon entry into the return-air system and distribution to classrooms with recirculated room air can result from, for example: subslab return air ductwork, unducted return-air plenums in the drop ceiling that are open to the subslab via open tops of block walls, and air intakes for unit ventilators that are open to the soil or floor/wall joint.

Many schools have not been designed to supply conditioned outdoor air to occupied spaces and, as a result, do not have the option for HVAC pressurization with current system design. Typically with such schools the fresh air was intended to be provided through above-grade cracks and openings such as windows. However, many of these schools have been retrofitted for energy conservation, decreasing the amount of outdoor air infiltration from above grade.

If schools operate an exhaust fan for ventilation purposes or to remove odors or chemicals and provide insufficient makeup air, significant negative pressures can result. This will exacerbate radon entry into the building through below-grade cracks and openings. Limiting use of fans that cause depressurization may help to reduce radon entry; however, pressurization of such schools through the HVAC system to prevent radon entry will likely require costly changes to the system. It is recommended that long-term HVAC plans follow ASHRAE Standard 62-1989 (4); however, installation of a SSD system may be the most appropriate step for reduction of radon levels in these types of schools.

Subslab Pressure Field Extension (PFE) Measurements

This section discusses suggested approaches and interpretations of PFE measurements in schools. Although the general principles are similar to those applied in house diagnostics, some circumstances are specific to schools. An understanding of subslab PFE in houses is assumed. (Reference 1 provides additional details.) PFE measurements should be performed under conditions that represent the typical pressure relationship of the building, since an effective SSD system must overcome all these pressures.

The first step in determining the potential effectiveness of a school SSD system is analysis of the building plans to determine the locations and types of footings and thickened slabs. If the plans are unavailable, some of the necessary information may be obtained during the building inspection. It is also crucial that, as discussed above, the locations of all plumbing and electrical lines be identified before drilling into the slab.

Subslab Aggregate Indicated on Plans - No Subslab Barriers. If the plans indicate that there is a continuous layer of clean, coarse aggregate underneath the slab, subslab PFE should be measured both to ascertain the presence of aggregate and to design an optimal SSD system. A centrally located suction point (e.g., in the corridor or on the corridor side of a classroom) will typically maximize the coverage of the SSD system. Experience has shown that, under such conditions, depressurization from one suction point can mitigate approximately 1,400 square meters. Experience has also shown that, if PFE measurements at a given test hole show a minimum pressure of -0.001 inches of water (-0.25 Pascals) with the vacuum test, depressurization in the test hole will often increase when the SSD system is installed (6).

Subslab Aggregate Indicated on Plans - Subslab Footings Surround Classrooms. Experience has shown that under such circumstances PFE will, at best, reach across one below-grade wall. (For example, a suction point in one classroom may extend into adjoining classrooms and the corridor.) However, many schools that have below-grade walls surrounding all sides of each classroom will require one suction point in each room. PFE will need to be evaluated on a case-by-case basis. If PFE measurements indicate that depressurization in some areas may be marginal, it is advisable to install a capped tee in the mitigation system in each area for potential addition of a suction point(s).

Where below-grade walls surround three walls of a classroom, PFE will typically be measurable far from the suction hole if there is an adequate layer of clean, coarse subslab aggregate.

No Subslab Aggregate. In schools with no subslab aggregate or with a large amount of fines mixed in with the aggregate, multiple suction points will probably be required in each classroom. Use of a high suction fan and excavation of large suction pits will also help to increase PFE. If subslab PFE is nonexistent or very poor (i.e., less than 3 meters), one must consider the acceptability of multiple suction points in a classroom.

Design of SSD System. System design will depend on the results of the PFE measurements and on other important factors including building codes (with regards to penetrating firewalls, etc.), convenience, and aesthetics. For additional details on SSD system design, such as fans and piping, consult Reference 1.

SUMMARY

School buildings have a number of physical characteristics that make their mitigation different, and typically more complex, than houses. These characteristics include: building size and substructure, HVAC systems, and locations of utility lines. These physical characteristics can influence radon levels in the building since they affect radon entry routes, building pressure differentials, and radon mitigation approach.

Radon mitigation research in schools has shown that the following diagnostics procedures and measurements are important in understanding a school's radon problem and potential solution: review of radon measurements; review of building plans including structural, mechanical, plumbing, and electrical; investigation of the school building to assess potential radon entry routes and confirm information cited in the building plans; analysis of the HVAC system and its influence on pressure differentials and radon levels; and, for schools considering installation of a SSD system, subslab PFE measurements.

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ACKNOWLEDGMENTS

The authors would like to thank all the school personnel who invited us to conduct radon diagnostics measurements in their schools.